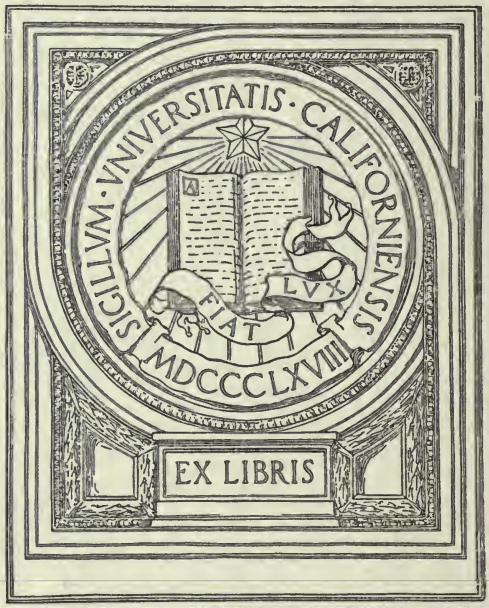

RECLAMATION AND PROTECTION

OF

AGRICULTURAL LAND.

ON THE

RECLAMATION AND PROTECTION

OF

AGRICULTURAL LAND

BY

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PREFATORY NOTE.

THE following paper on the Reclamation and Protection of Land was communicated to the Highland and Agricultural Society of Scotland, and published in the last volume of the Society's Transactions, and is republished in its present form with the sanction of the Directors.

The Publishers conceive that the subjects briefly treated in the following pages are of sufficient general interest to agriculturists to warrant separate publication, while the chapters on the reclamation of land from the sea afford information in some respects new, and likely to prove useful on a branch of agricultural engineering which ere long may engage general attention.

To show the interest now taken in works of reclamation, it may be stated that in France the Paris Society for the Encouragement of National Industry has invited competitive papers to be given in during the year 1874, "On Reclamation of Land and Embankments;" and in America the same subject has been brought before the Government Department intrusted with the coast survey of the United States. In England also many

writers have of late, through the newspaper press, been urging the Government to take advantage of their right to the foreshores of the country by affording every possible facility to public companies and landed proprietors to embark in reclamations.* Some of those English writers seem to maintain that by wholesale national reclamation the agricultural resources of the country may be made to keep pace with its growing population, so as to check our increasing dependence on foreign countries for supplies of agricultural produce.

The following short treatise, however, demonstrates that all schemes of reclamation are not *necessarily* good agricultural speculations; and that it is only where the estimated value of the land to be gained from the sea is deduced from well-ascertained physical facts, and the works by which it is to be reclaimed and protected are based on sound engineering principles, that the result may safely be relied on as successful.

* See "Times," "Daily Telegraph," "Edinburgh Courant," &c., for January 1874.

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INTRODUCTION.

It is needless to inquire at what date and in what country attention was first directed to the reclamation and protection of land, as such an inquiry would not afford any satisfactory or useful result. But it is well known that the subject has long engaged the attention of engineers, and is viewed as of great practical importance by agriculturists. It has occurred to me, therefore, that an exposition of the state of our knowledge regarding this branch of agricultural engineering, founded on personal experience and study of the principal rivers and estuaries of the United Kingdom, may prove not uninteresting to the members of the Highland Society.

In offering this exposition of an extensive subject, it may be as well in the outset to explain, that I do not propose to describe those gigantic land-making and land-improving works carried out in early times in some foreign countries, and to which the kingdom of Holland, for example, may be said in a great measure, if not altogether to owe its existence, and the fertile banks of the Po their productive-

ness. A wide enough field of observation may be found within our own country, where, in prosecuting the ordinary pursuits of agriculture, thousands of acres of barren sands and flooded marshes have been converted into valuable land, and many rivers have been confined within reasonable bounds by engineering works of greater or less magnitude. Neither do I propose to discuss questions of hydraulics, which belong to pure engineering, or to state details of construction that have already been given in many interesting papers in the Society's Transactions, describing individual reclamation improvements. My object is rather to show, generally, in what way engineering is connected with agriculture in the important work of reclaiming and protecting land—what are the varied conditions of exposure and locality which render such protection necessary,—and what description of work is best adapted to each particular case, for the information not so much of engineers, as of agriculturists, to whom this communication is specially addressed.

The general feature of all low-lying lands intersected by rivers, of all marsh lands on the borders of tidal estuaries, and of some extensive tracts of land along the sea-coast, is their liability to injury, and their need of protection by artificial works, and the elements with which the engineer has to contend in effecting agricultural improvements in such situations are, *river-currents and floods*, *tidal-currents* and *sea-waves.* The subject, therefore, with which we have to deal embraces distinct compartments, each of which has its own characteristic features and treatment, and it may perhaps be most conveniently considered under the following general sections:—

I. The protection of land from the wasting action of rivers.

II. The prevention of rivers, when in flood, overflowing low-lying tracts of land.

III. The reclamation and protection of tidal lands situated on estuaries; and

IV. The defence of sea-shores from the action of the waves.

Large tracts of peat bog, such as Blair Drummond moss in Perthshire, and of waste land, such as the Fylde of Lancashire, as well as land submerged by lochs, as Loch Leven in Kinross-shire, have been reclaimed and brought into cultivation; but these improvements having been effected by drainage, do not, it will be seen, come within the range of the topics treated of in this paper.

CHAPTER I.

THE PROTECTION OF LAND FROM THE WASTING ACTION OF RIVERS.

Abrading action of rivers, illustrated by the Forth.—Winding rivers may be improved by "cuts."—Remedial works for checking abrading action of rivers—by making the surfaces of the banks smooth and uniform—by planting willows and reeds—by depositing stones on the face of the banks—by timber pile-work and the deposit of fascines of brushwood.—Examples of river embankments.

In considering the first of the topics to be discussed, which refers to the wasting action of rivers on their banks, the following general statements may be made:—

1. The scouring or abrading action of a stream is influenced by its velocity.

2. The velocity again is influenced by the fall or slope on its surface.*

3. The effect of the scouring action on the adjoining banks is further influenced by their geological formation,—experiments having shown that ordinary sandy soil is moved by a current having a velocity of about half a mile an hour, and that a current of about one mile per hour will move fine gravel, while heavy gravel resists a current of upwards of two miles per hour.

* When a river is in train also by its hydraulic mean depth.

An illustration of the abrading action of small rivers or streams may be found whenever they traverse a flat alluvial tract of country. If the velocity of the stream be sufficiently great to abrade the banks, it will commence an attack at some vulnerable point where the soil is very soft. This soft bank soon assumes a concave outline, round which the stream sweeps and impinges with violence directly on the opposite bank, which, in its turn, soon yields to the abrading action, and another concavity is hollowed out in a direction opposite to that first formed. In this way the river, deflected from bank to bank, enlarges its bends and lengthens its course. But as the length of its course increases, the gradient and velocity of the stream are reduced, and its abrading power, which, as we have said, depends on the velocity, may ultimately by successive bends be so diminished that the original destructive current becomes a placid stream, incapable of making further violent inroads on the banks; and to this state of permanent conservation many of the tortuous, sluggish rivers to be seen meandering through the flat meadow lands of England have been brought, but the sluggishness of such streams may have been attained at a considerable sacrifice of valuable land. Perhaps the most notable instance, on a large scale, inScotland, of a winding river is the Forth. The straight distance from Stirling to Alloa is about 5 miles, which with a fall of 13 feet between the two places gives a gradient of 2 feet 7 inches per mile, but following the course of the river the distance is about 10 miles, giving a gradient of about 1 foot 3 inches per mile, while the land occupied by the "Links" or "bends" amounts to nearly 500 acres unavailable for cultivation. In referring to this case, I do not wish in any way to

countenance the idea, that either in the interests of agriculture or navigation it would be profitable or desirable to form a straight cut from Stirling to Alloa. I only refer to it as being perhaps the most remarkable instance, in our country, of a winding river which has attained a permanent course, and its bed and banks a state of stability.

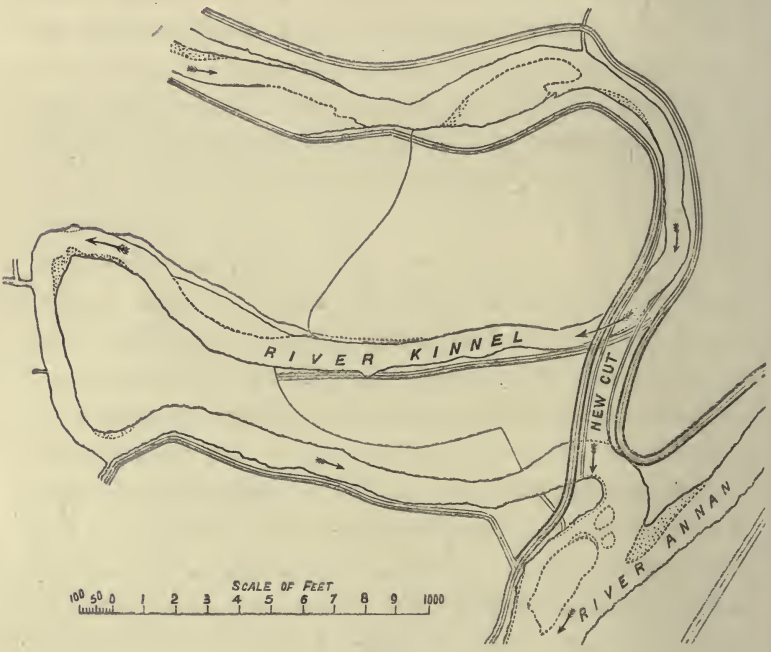

Fig 1.

There are, however, many winding rivers where a "cut" may be made with great advantage, as at the river Kinnel, in Dumfriesshire, which is shown in fig. 1. That "cut," which was formed under the direction of Messrs D. & T. Stevenson, was made chiefly for

the better regulation of the boundaries of the march lines of the adjacent properties. It will be seen that the river was, in that instance, carried through a narrow neck of land measuring about 500 feet, and saving a *detour* of upwards of 4500 feet. Fig 2. is a cross section of the new channel. To the effect of such alterations on a river's banks and floods I shall have occasion to refer hereafter, and merely add here that the cut at the Kinnel was formed twenty years ago, and Sir William Jardine,

Fig 2.

through whose property it was made, informs me that it "has proved most satisfactory in every respect, and that the banks have stood without any necessity for repair."

The violence of scouring action is also well illustrated on rivers with steep gradients and high velocities flowing through a channel having alternately high gravel scars and flat gravel banks. Such, for example, as the Ae in Dumfriesshire, which at some places has a fall of 45 feet per mile. In all such cases, the river highly charged with gravel has its power of erosion greatly augmented, and very speedily hollows out its solid banks, and makes serious inroads on the adjoining property, and, if unchecked, will continue to abrade the banks to an extent that may interfere with existing roads and fences, and thus prove highly prejudicial. In my own experience I have found both fences and roads carried away, to the great inconvenience of the public and damage to property.

The remedial measures for checking the abrading action referred to are, the planting of willows or reeds on the banks, the deposit of broken stones of sizes varying with the exposure, timber piling and planking, and the deposit of fascines or faggots of brushwood. It may, however, be safely affirmed that nothing tends more to the protection of a river's banks than a uniformly smooth surface. The water in such a case meeting no obstruction, glides gently past without resistance. But if the banks have from neglect got into a rugged, uneven state, they are comparatively easily excavated by the current; and it may be well to keep in view that an inoffensive, sluggish stream, which passes quietly along a smooth bank, will become a formidable *excavator* if there be opposed to its otherwise gentle flow a succession of rugged protuberances. Each of such protuberances, though on a small scale, acts in the same way as a jetty, the water is heaped up on its upstream side, and flows with increased velocity and scouring power round its extremity, and the river thus becomes more destructive in wasting its banks.

In all cases, therefore, where such streams intersect valuable property, all irregularities and incipient wastings in the banks should be repaired without loss of time after the occurrence of each flood.

In many cases, however, such repairs cannot be conveniently made until the wasting has proceeded so far as to render necessary some of the works to which I have referred,—such as the deposit of stone, broken like large road metal, in sufficient quantity to make a new face to the river's bank, which is a simple and often efficient means of defence, and should in all cases be first tried. But where the current is strong

enough to sweep away road metal, or even large material, and especially where it has formed an acute bend in the bank, and hollowed out a deep pool in the bed of the river, works of a more expensive character may be required such as I have shown on the accompanying cut, fig. 3, which has, with

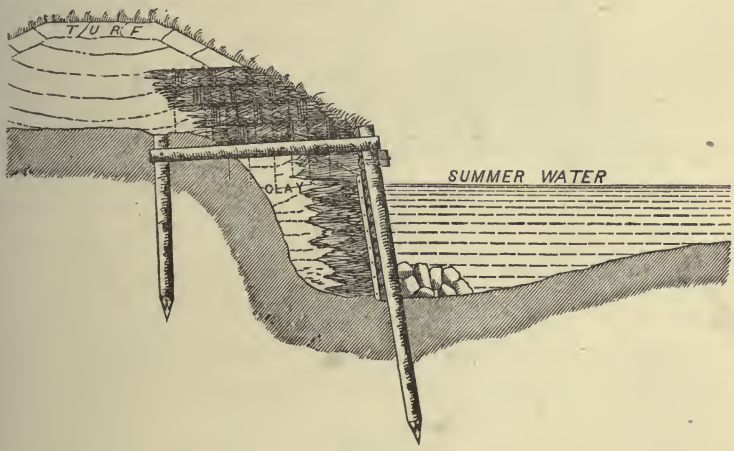

Fig. 3.

modifications to suit the localities, been executed with good effect. It consists, as will be seen, of round piles and cross planking with back piles and cross ties backed with faggots and clay. Upon the top of this rest layers of faggots, the whole being surmounted by a turfed embankment, and protected at the bottom by rubble stones. Figs. 4 and 5 are sections of other forms of protection adapted to situations where the depth of water is not so great, and with some modification in the arrangement and sizes of the materials to suit special circumstances, I have found that the styles of con-

struction shown in these three sections were useful in many cases where protection was necessary.

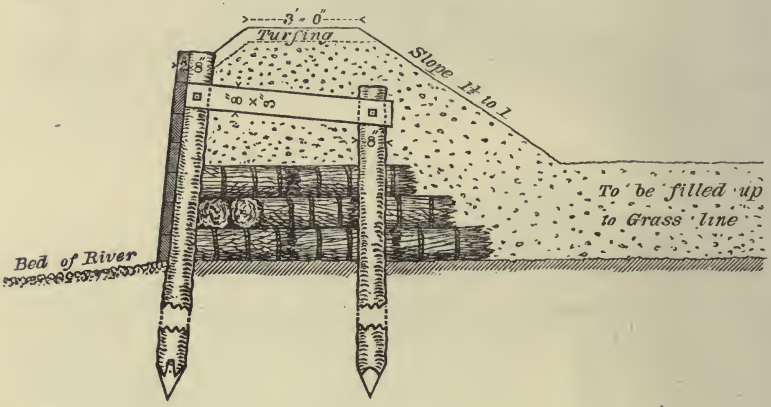

Fig. 4.

I may only repeat, on this branch of the subject, that early careful attention may often avert the necessity of subsequent

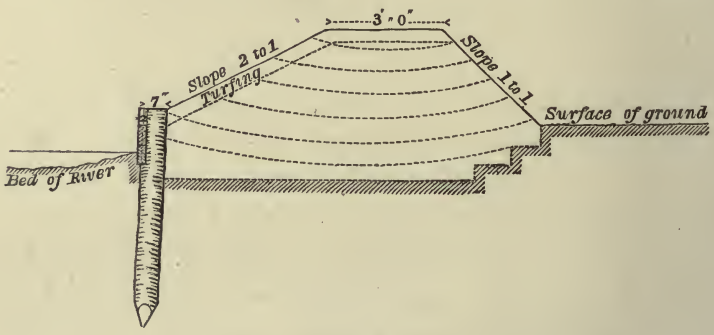

Fig. 5.

expensive works, and that the timely planting of a *few willow saplings* may avoid the driving of many *piles of full-grown timber.*

The junction of two rivers is often the occasion of much injury, by causing extensive diversions of the channel, particularly if the axes of the two streams form a large angle at the point of junction, as will be seen from fig. 6, in which the

Fig. 6.

arrows represent the junction of the Ae and Kirkburn, and the same objectionable feature will be seen in the junction of the Kinnel and the Annan, to which I have already referred at page 6. In such cases, according as either river happens to be in higher flood, the stream below the junction is forced to one or other side, and when the valley through which it flows is broad, and the banks are composed of soft material,

the river may be found shifting its channel from side to side of the valley, and devastating all the intervening land. This may sometimes be obviated by diverting the courses of the rivers immediately above their junction, in such a direction and to such an extent that at the point where they unite the direction of their respective currents should be as nearly as possible parallel. But the configuration of the ground and the boundaries of the adjacent properties may present such difficulties and involve such cost as to render such a work practically impossible, and, in that case, the river must be left to take its course, and the land within reach of its flood lines abandoned for all agricultural puposes.

CHAPTER II.

THE PREVENTION OF RIVERS, WHEN IN FLOOD, OVERFLOWING LOW-LYING TRACTS OF LAND.

Flood-Water passed by rivers bears no constant ratio either to their summer water discharge or to the drainage area.—Ordinary and extraordinary floods.—Quantity of water passed off different lands during floods.—Morayshire floods.—Cause of flooding of rivers.—Remedial measures for checking flooding.—Navigation works on the lower reaches of rivers have diminished flooding.

THE second branch of the subject relates to the protection of low-lying lands against the effects of river floods.

With reference to such inundations, I may here repeat what I have elsewhere stated,* that the quantity of flood water passed by rivers bears no constant ratio either to their summer water discharge or to their drainage area. This conclusion is the natural consequence of the very different geographical and agricultural characteristics of the districts through which rivers flow.

The drainage area in one situation, for example, may include large tracts of hill country, having steep and scantily soiled slopes, from which the rain is readily discharged. In other places the surface may be flat, or gently rising deeply soiled land, absorbing much of the rain that falls, and giving it off

* The Principles and Practice of Canal and River Engineering. A. & C. Black, Edinr., 1872.

only by slow degrees. The discharge of other districts, again, may be much influenced by their geological formation and the absorbing power of the underlying strata.

Agricultural improvements, also, exert an important influence on the drainage of land, large tracts of sheep grazing pasture, for example, being less absorbent than an equal area of well-drained arable land. Again, all rivers which flow from lakes may be said to have natural reservoirs at their source for the storage of surplus water, which tends to check the floods in the low country. But this, again, is not always the case, for it has been found at the Tay, which flows from Loch Tay—a sheet of water 14 miles long and three-quarters of a mile broad—that in heavy westerly gales the wind acting on so long a reach heaps up the water at the outlet, and, if combined with heavy rainfall, greatly increases the flood in the river. It thus appears that there are so many local circumstances which affect the frequency and severity of floods in different localities, that no rule generally applicable can be stated regarding them. What may be termed the *ordinary* floods of rivers generally occur with heavy rain and melting snow, for then the bed of the river has to discharge a compound flood made up of what is falling in the form of rain and what is draining off the land as melted snow. But *extraordinary* floods, affecting a limited area, may occur at any period in connection with thunderstorms, and it is the fact, that some of the most remarkable floods, such as that in the northern counties of Scotland in 1829, occurred in August, and were due, not to a sudden thunderstorm, but to the continuance of heavy rainfall over a large district of country, and in the instance referred to, 3¾ inches of rain fell

between 5 o'clock on the morning of the 4th and 5 o'clock on the morning of the 5th of August. Various formulæ have been suggested for calculating the flood discharge due to a given area of land, but the information as to the amount of flood water said to have been discharged from different districts of country is so discordant, due no doubt to the varied physical conditions above noticed, that it seems to me to be impossible with elements so variable to found any formula that can be generally useful.

It may not be uninteresting to state, however, that the quantity of water passing off during high floods is variously given by different authorities at from 1 foot to nearly 100 cubic feet per minute per acre for the districts in which the observations were made. The highest gauging I have ever got was 15 cubic feet per minute per acre from a town district of 630 acres, after three days of nearly continuous rainfall. Thunderstorms, however, discharge a very much greater amount during their short duration, and it is stated that, in August 1846, during a thunderstorm in London, 3·3 inches fell in two hours and twenty minutes, being 85 cubic feet per minute per acre. I think that, with our present information, the only general result to be gathered from records of floods is, that *the flood discharge bears a higher ratio to the ordinary discharge in small than in large rivers.* This is due to the fact that in a small river a rainfall may affect and swell every one of its drains and feeders at the same time, whereas, in a larger river the rainfall may be confined to one district only, and thus the flooding is modified in its amount. It follows, therefore, that the smaller streams or burns intersecting a property at a place far removed, it may be, from the main stream, may, especially

if their slope and sectional area be small, be subject to sudden and destructive floods bearing a very high ratio to their ordinary discharge.

But under whatever circumstances and to whatever extent the floods in rivers take place, their destructive effect on property is too well known to require illustration, and the means of securing the prevention or amelioration of such disasters cannot receive too much attention. In using the words prevention or amelioration, it is perhaps almost unnecessary to explain that I do not refer to floods of such calamitous and overpowering violence as that already alluded to, which occurred in Morayshire in 1829, and has been so well recorded by Sir T. Dick Lauder, as "bordering on the marvellous, and ruining property to an extent that defies calculation."* On that occasion the Spey, where fully a mile wide, rose 10 feet 2 inches, and where half a mile, 13 feet 9 inches. The Doveran rose 18 feet; the Dee in Braemar, with an average breadth of 130 feet, rose from 15 to 16 feet; and the Findhorn at some places rose as much as 50 feet above its summer water level. Such a visitation is clearly beyond all human control, but the remarks I have to offer refer to certain periodic inundations which, in some localities, are of occasional if not frequent occurrence, and are regarded as phenomena that may be expected at least every two or three years, almost as certainly as the biennial equinoctial spring tides of the ocean; and though the districts over which such occasional floodings extend may form but a small portion of the agricultural area of the country, still the very

* Account of the Morayshire floods of 1829.

fact of their periodic occurrence to a greater or less extent in many rivers gives the subject a general interest.

Perhaps it may seem almost unnecessary to say that flooding takes place when the combined sectional area of a river channel and the fall on its bed do not afford sufficient discharge for the passage of the drainage water. The obstruction due to deficient sectional area may be lessened, or perhaps altogether removed by enlarging the channel of the river, while that due to insufficient fall may often be removed by making a *short cut* instead of a long detour, as already noticed at page 6, and thus increasing the slope of the surface and the velocity of the current, and when such operations cannot be carried out, or do not either singly or combined afford sufficient relief, recourse must be had to artificial embankments.

In forming straight cuts to shorten a river's course and increase the fall on its surface, and, consequently, its velocity, care must be taken that the inclination be not so much increased as to produce a current so rapid as to injure the banks of the new cut; and as their liability to injury (as explained in treating of the abrasion of banks) depends on the materials of which they are composed, it is not possible to lay down any rule of universal application in deciding what rate of inclination may safely be adopted. The formation of a new cut or channel is, however, a work that should not be undertaken without careful consideration of all the circumstances, as such a work may in some cases prove injurious to the bed and banks below the point where it joins the original course of the river, and thus prove detrimental to the interests of adjoining proprietors.

I may here remark in passing, that the currents of large rivers vary as the place of observation is narrow or wide, and also as the flow is that of ordinary or of flood water, and that the velocity of such rivers as the Thames, the Tay, or the Clyde may, according to their different conditions of flood, be found to vary from about one mile per hour as a minimum, to about three miles per hour as a maximum velocity. Smaller rivers with steeper slopes have higher velocities. I have found the currents of such rivers as the Water of Leith, for example, in flood at places where the gradient of the bed varies from 25 to 32 feet per mile, to run at rates varying from $3\frac{3}{4}$ to $5\frac{3}{4}$ miles per hour. Still more rapid currents will be found where the bed is still steeper, until we reach the mountain torrent carrying everything before it in its rapid descent.

The details of two very good examples of checking the flooding of land by widening and straightening rivers, and thus increasing their power of discharge, are to be found in the Transactions of the Society—the one an account of the improvement of the pasturage lands on the Torran in Caithness, by Mr James Purves,* and the other a paper by Mr Blaikie on the Improvements of the Don in Aberdeenshire.† But it is not often that the divisions between the properties of conterminous proprietors admit of extensive deviations of a river's course, and even when no such difficulty occurs, the formation of the country itself may render such a work impracticable. Proprietors are, therefore, generally obliged to resort to artificial embankments for the protection of their own lands, and such works are, as is well known, extensively employed for that purpose. Their proper construc-

* Series iv. vol. ii. p. 439. † Ibid. ii. vol. ii. p. 75.

tion has received much attention, as may be learned from the numerous papers describing them and their effects, as executed in different localities, which have appeared in the Transactions, among which I may refer to the communications of Mr Hamilton,* Mr Udney,† Mr Menzies,‡ and more recently to the papers of Mr Sutter,§ and Mr Milne,‖ communicated to the Society in 1858.

With reference to protecting banks, it may be stated that experience has shown that they should invariably be placed, if practicable, at such a distance from the edge of the river as to leave a solid foreshore. Care should be taken that no abrupt angles or bends be formed, but that their line of direction should be carried in easy curves. They may be composed of almost any firm materials which will compact solidly together, the best perhaps being a mixture of clay and sand. All combinations of walls of masonry with embanking, which have sometimes been recommended, should invariably be avoided, as it is impossible to effect any proper bond or union between the earthwork and the masonry, and such composite structures are likely to result in failure. The surface of all banks, particularly that next the river, should be turfed, and the back slope sown with grass as speedily as possible, and no hedges, brush-wood, or trees should be planted on artificial embankments. When the subsoil on which the bank is formed is gravelly and porous, trouble may occur from the passage of water under the embankment, and, in such cases, it may be found necessary to sink a trench and

* Series ii. vol. ii. p. 97.
† Ibid. vol. vii. p. 100.
‡ Ibid. vol. vi. p. 489.
§ Series iii. vol. viii. p. 317.
‖ Ibid. vol. viii. p. 427.

fill it with clay puddle. The ordinary dimensions for such embankments are that they rise about 2 feet above flood level, that they have a top width of 3 feet, with a slope of 3 to 1 towards the river, and 2 to 1 towards the land; it will hardly be desirable to attempt to construct such defence flood embankments when they are likely to be exposed to a greater pressure than 4, or at most 5 feet, as their cost will then become too great, and the difficulty and risk of construction too formidable for private enterprise.

As the effect of all such embankments is to prevent the river from spreading over flat tracts of country, so their tendency is to cause a greater discharge and higher velocity through the natural channel of the river, and to increase the abrading power of the current on the bed and banks. Again, if the works of protection include only one side of the river, the result may be to increase flooding on the opposite bank, if it be not similarly protected. Hence such operations on the part of proprietors have led to serious legal proceedings, which renders it advisable not to embark in the formation of such works without careful consideration of the consequences.

The remarks I have offered refer, it will be seen, to works made purely in the interests of agriculture. But the beneficial effects which have followed extensive navigation improvements in lessening the floods in some of our large rivers are highly important and deserving of notice.

The works executed in improving the navigation of the lower reaches of the Tay, the Clyde, and the Tees, have lowered the level of the low-water line, and the power of discharging flood waters with an ebbing tide; and, accordingly, we find ample

proof that the flooding of the lower districts of the towns of Perth, Glasgow, and Stockton, the ports of these rivers, is sensibly diminished both in frequency and extent. On the other hand, the danger of rashly obstructing the flood water channels of rivers is well illustrated on a large scale in many railway and road-works throughout the country, where lines of railway or road have been injudiciously carried across flat *haugh* land on solid embankments of earth-work. Cases must suggest themselves to the recollection of the reader, where great injury has followed the construction of such works,—injury which could only be remedied at great expense by enlarging the water-ways of bridges, and converting solid embankments into open viaducts for the free passage of flood water—a relief to the submerged land which I have recommended in several cases where I have been consulted.

CHAPTER III.

THE RECLAMATION AND PROTECTION OF TIDAL LANDS SITUATED ON ESTUARIES.

Object of tidal reclamations.—Interest taken in the subject at present.—Dee reclamations.—Land-making schemes and navigation not always compatible.—"Warping."—Amount of matter held in suspension in different estuaries.—Land made by tidal deposits a slow process.—Level at which vegetation appears.—Interests of agriculture and navigation are often identical.—"Warping" may be hastened by very slight works.—Time at which marshland is fit for inclosure.—Agricultural treatment of reclaimed land.—Conditions which are necessary to profitable reclamation.

WHAT has hitherto been said refers solely to regulating or controlling the flow of rivers. The next branch of the subject, embracing the reclamation of lands on the shores of estuaries, introduces a different feature; and although much that has already been said regarding currents and embankments will be found to apply to reclamations in estuaries, yet the lands we are about to consider in one respect at least differ from those already noticed, inasmuch as, being within sea mark, they are subject to all the influences consequent on the constant *flow* and *ebb* of the tides.

The object of such works is to reclaim those low lying sandbanks, mudbanks, and marshes to be found in all estuaries and outfalls of rivers which are left dry on the receding of the

tide, and are thus, according to their level, rendered more or less easily convertible into pasture or corn-growing land.

It is not for the agriculturists of the British Isles alone that the subject of reclamation has an interest. Even in the United States of America, with all its vast tracts of unoccupied land, attention is now being directed to gaining land on the margins of the bays and estuaries on the eastern shores of the country; and the National Society of Paris have recently invited communications to be made to them during the year 1874, "on the embankment and reclamation of land from the sea." Still more recently, Mr Rintoul, of Kingston, in East Lothian, has suggested that our Government might profitably make use of the Crown right to the foreshores within high-water mark by forming sea embankments. That the subject is exciting much attention cannot therefore be doubted, and that reclamations have in certain situations and under certain circumstances been successfully carried out has been fully established. But it would be very erroneous to assume that every foreshore uncovered at low water may *profitably* be converted into arable land; and as there is reason to believe that much misconception exists on the subject, I have thought it might be useful to discuss at some length our experience of the methods adopted in forming reclamations, and the practical results which have been obtained under different physical circumstances.

The area reclaimed from the estuary of the Dee, which is now fertile land, was originally pure sandbank covered by all spring-tides, and utterly unavailable for any useful agricultural purpose, and as it is a good example of such tidal reclamations, it may be interesting to give a brief outline of what has there

been accomplished. The River Dee Company, incorporated by Act of Parliament in 1732, has from time to time reclaimed from this tide-covered waste a large tract of land extending to about 4000 acres, which is now in full cultivation; and alongside of this gradually gained territory the river has been conducted from Chester to near Flint, for the purpose of navigation, in a narrow canal of about 8 miles in length, and 400 feet in width. A considerable portion of land has also been reclaimed on the Flintshire side of the estuary, though not by the proprietors of the Dee Company; and it is believed that the aggregate amount which has, from first to last, been gained from the sea is about 7000 acres.

The process followed in carrying out these land-making works was to construct a high bank rising 9 feet above the level of high water, so as to confine the river to the south side of the estuary. The tidal water, which was admitted to flow freely between this bank and the north coast, gradually deposited layer after layer of sand and silt, and, in fact, shut itself out; and so soon as the surface had attained a sufficiently high level, a cross bank was constructed between the main embankment and the north shore, and thus the large area as above stated was *bit by bit* reclaimed. The reclaiming banks were gradually strengthened and pitched with stone on the outer face, and substantial self-acting sluices were formed, which close against the ingress of the rising tide, but being open at low water, allow the drainage water to escape from the reclaimed ground, some of which is still below the level of high water.

It may here be well, in passing, to observe, that land-making schemes constructed on such a principle prove generally in-

jurious to navigation, and that of the Dee Company which I have described is no exception. But it is of greater importance, perhaps, to state that navigation improvements, as will be shown hereafter, may, if judiciously carried out, be made to promote the acquisition and protection of land as well as the interests of navigation, as for example, at the Ribble and the Lune in Lancashire, and thus to serve at once the two-fold interests of navigation and agriculture. I know from experience, that had proprietors of land and conservators of navigations, in many tidal estuaries, worked harmoniously together in jointly carrying out such improvements as would have benefited both interests, much unnecessary litigation might have been prevented, and a result more satisfactory to both parties might have been attained. Such a land-making scheme as that of the Dee can be successfully taken up only by a powerful company. But many useful reclamations have been effected without recourse to such extreme measures, advantage being taken of a slow and almost unseen process, whereby, under favourable physical circumstances, aided sometimes by the help of very slight appliances to hasten and secure the deposit, the surface of the banks is gradually raised by the alluvial matter left by each receding tide, and it is often in carrying out these isolated and gradual reclamation works, that the interests of proprietors and conservators come into collision, and that a joint plan of works would be very desirable.

The gradual process of reclamation to which I have alluded as often resorted to by proprietors, is termed "warping." The tide is permitted to flow freely over the surface, and whatever matter is deposited at slack tide contributes to the accre-

tion, so that the rate at which the process of reclamation goes on must depend on the quantity of matter held in suspension and the shelter of the situation, so as to give sufficient duration of still water for its deposit.

The amount of matter held in suspension varies, as may be readily supposed, in different estuaries; in some situations it is derived from the action of the sea on a wasting line of coast, in others from alluvial matter brought down by the river, and in most cases, perhaps, from both of these sources of supply. The size of the detrital particles carried by the currents of estuaries or rivers depends on the velocity of the stream, the nature of the bottom along which the detritus is moved, as well as the shape of the particles of which that detritus is composed, and varies with the special circumstances of each locality. Observations have been made on the quantity of solid matter held in suspension by different rivers, and repeated by various authors; but these observations have invariably been made in water taken from the main stream, and cannot be held to apply to such cases of reclamation as we are considering, the substratum of which is slob composed of the finest silt, and submerged only by sluggish currents, incapable of leaving anything but the finest matter deposited on its surface. It has been stated that marshes on the Seine require twelve years to rise to the level of high water, thirty years on the Bay of Vays, and eighty years on the Scheldt, and similar variations are to be found in statements made by various authors. Mr Oldham * states that at Sunk

* On Reclaiming Land. By James Oldham, Min. of Proc. of Inst. of Civil Engineers, vol. xxi.

Island, on the Humber, the reclamation was hastened by constructing a temporary or preliminary bank with a sluice, and permitting the tidal water to flow over the land at high water, when the sluice was closed, and the whole of the mud held in suspension deposited, after which the sluice was raised so as to allow the water to escape, leaving behind its load of rich deposit. In this way he obtained in two and a half years a deposit of three feet. The most rapid deposit which has come under my own notice, was near the mouth of the Avon, at the Severn, where the channel between Dumball Island and the shore was silted up to the extent of 32 feet in seven years. As a general rule, I have found that the heavier sands and deposits are found on the banks at the mouth of the estuary, and the particles are lighter as we recede inwards.

Such reclamation of land, however, as is due to the deposit left by the free and unobstructed flow of the tide is a very slow process, because in proportion as the banks rise, they are more seldom covered by the tide, and, moreover, the materials deposited in the higher parts of the banks are exceedingly fine, being carried only by the slack water of highest tides, and it is not until the surface has attained a pretty high level that it can be regarded as land in any agricultural sense. It has been very generally found in open estuaries where the reclamation is permitted to go on undisturbed by encroachments of the river, that vegetation, in the form of patches of aquatic plants, begins to appear when the bank has reached the level of high-water mark of neap tides. As it rises above this level, its surface will be found to be more or less covered with patches of

Fig. 7.

vegetable growth up to high water of spring-tides, where the vegetation attains a continuity and the land a firmness from the roots of decaying plants, such as to entitle it to be termed "marsh-land," and when the surface is not covered with reeds and rushes it is fit for grazing. Below the neap tide level, again, the surface is what is called "slob," consisting of sand covered with mud, with no vegetation whatever, and lower down there will be found sand more or less pure according to the situation. The disposition of those different limits will be seen from the accompanying section, fig 7. The upper or "marsh" portion of the section corresponds to what in England are locally termed "salt-marshes" and "outmarshes," and in Scotland simply marshes. The aquatic plants growing on these marshes are found to vary according to their position. If near the sea the plants predominating are those which flourish in saline soils, such as marsh samphire, sea-pink, &c. If the situation be more estuarial, and more within the influence of fresh or brackish waters, reeds, sedges, flags,

and rushes will prevail. The surfaces of these naturally formed tracts of ground are, as may be gathered from what has been said, on a pretty high level. I found the marshes of Salt-area, Coleway, Ovangle, and Overton on the Lune, and of Clifton, Howic, and Hesketh on the Ribble, to average about a foot below high water of ordinary spring tides.

In connection with this gradual accretion and formation of land, and the sudden changes which, if unprotected, it sometimes is destined to undergo, it may be interesting to the geologist to state as having come under my own observation, that a sandbank covered by every tide may, by a happy diversion of the river, become in a few years useful pasture land; while, on the other hand, by another capricious change of the river's course, the apparently permanent pasture meadow, the growth of years, may suddenly disappear in a few tides, and the spot where cattle have been grazing to-day may to-morrow once more be the main channel of the river. Instances of such sudden changes I have witnessed both on the Ribble and the Lune before the courses of these rivers were controlled and directed by proper works.

In my treatise on "River Engineering" I have shown that in many cases the interests of navigation and agriculture are identical, and that the erection of training walls, such as shown in fig. 7, by guiding the river, and thus improving the navigation, may, at the same time, greatly promote the interests of agriculture, by rendering such wholesale destruction as that to which I have alluded impossible, and by converting reclaimed marsh land into *permanent* property.

On the Tay and at other places the process of warping is

hastened by driving double rows of open pile work, and filling the intervening space with faggots of brushwood weighted down with stones, and as the surface rises additional faggots are laid down, till the whole is sufficiently elevated to warrant the exclusion of the water. Sir John Richardson has paid much attention to this on the Tay, and has communicated his experience to the Society's Transactions.* He advocates especially the filling up of runs or waterways caused by the running off of the receding tide, by running lines of stakes and faggots across them, and advises that these cross lines of stakes should be made lower in the centre, with a rise towards both ends, so as to prevent the water from escaping round the ends, and so forming new channels. He also strongly recommends all surface water from the adjoining land to be led by catchwater drains clear of the land proposed to be enclosed, or if that be impracticable, by a properly constructed outlet through it, so as in any case to prevent the water flowing over the surface of the marsh or slob land. Sir John Richardson tried very successfully the planting of small patches of bulrushes over the slob land, but from my experience as to the growth of vegetation in such situations as above stated, the planting of patches of bulrushes or marsh samphire need not be attempted at a lower level than about the high water of neap tides, and it does not appear that this was done on a lower level on the Tay. The tenure by which such marsh lands are held has been shown to be uncertain, excepting in estuaries where the river is confined by training walls; but even after such naviga-

* Series ii. vol. vi. p. 298.

tion works have been executed the land is still submerged by every high tide, and though this is not found to injure it for pasture, it renders it quite unavailable for tillage without works specially constructed to afford protection from floods, and provide for effectual drainage. The erection of all such works cannot be too carefully considered, and even after they have been constructed they have to be closely watched, and are often kept in repair at a constantly recurring expenditure. The remarks I have made at page 9 regarding the construction of river flood embankments apply generally to those for reclamation, and I need not repeat them here; but the cross section of such works must, of course, in all cases be regulated by the exposure.

In making estuarial reclamations, it is of importance to determine how soon marsh land may be considered fit for enclosure, and on this point my experience leads me to conclude that it is in general inexpedient to attempt to enclose land by permanent banks until, by gradual deposit and subsequent accumulation due to the decay of vegetable matter, its surface has reached about the level of high water of *ordinary* spring tides. I do not say it may not be done before this level is reached, for land has, within my own knowledge, been enclosed at a considerably lower level on some parts of the Tay, where the marshes covered by reeds in sheltered places were found to be fit for enclosure, though covered to the extent of from 3 to 4 feet at high water, and on the Forth still lower slob lands have been inclosed. But, as a general rule, it is safe to assume *that the higher the level of the land the greater is the chance of profitable reclamation.* The inducement to place a protect-

ing bank in deep water, is, of course, the enclosure of as large an area as possible. But greater extent of area may prove of little or no advantage if the larger portion of the enclosure is mere "slob" on a low level requiring a long period for its accretion. Above all, such enclosures require banks of great height and strength, which are more liable to be damaged, both in the course of construction and after completion, than a more unpretending, but perhaps in the end far more useful work formed in shallower water. I have found, in estimating the cost of banks proposed to be made on a low level, that the agricultural gain was not commensurate with the cost and risk attending their construction, while in some cases they would have proved prejudicial to navigation. Generally speaking, indeed, proposals to build banks in deep water including a large extent of "slob" have, in my experience, been found to be fallacious. But even though the reclamation be restricted to marshes that have attained a pretty high level and a fair solidity of surface, there are low "gulleys" or "swashways," as they are variously locally termed, kept open and deep by the flowing and receding tide; and if these gulleys are large, it is often troublesome to carry the embankments across them, for as the opening comes to be contracted by the gradual formation of the bank, the scour and depth of water are increased. In dealing with such cases, it may be found advisable, instead of closing the gap by extending the bank from either side, to deposit on the bottom fascines loaded with stones, and to bring up the whole surface of the bank across the gulley gradually.

In making enclosures in front of rapidly rising high land, difficulty may be experienced in consequence of land-water from

a higher level finding outlets within the embankment, and thus interfering with the thorough drainage of the reclaimed land,—an inconvenience which is not so likely to occur in such enclosures as are made in front of low lying tracts of country.

The time that must elapse before such enclosures may be expected to become ready for the exclusion of the tidal waters must, as we have seen, vary with the situation, the rate of accretion depending on the amount of suspended matter in the water and other circumstances, and even after the exclusion of the tide, a considerable period elapses before the land is ready for tillage. Many extensive tracts of "salt marshes" are never enclosed, and although covered to a depth varying from a few inches to a foot during high tides, they afford excellent pasture. But if the land is to be cropped, the water must, as already noticed, be wholly excluded.

The treatment of reclaimed marsh or slob lands in order to fit them for the purpose contemplated by their enclosure, belongs specially to agriculture, and not to engineering, and I am unable to offer any opinion which could be of any value on that subject. But, I think, it would be unpardonable were I to omit all reference to this important matter, especially as it has been very fully, and I should think judiciously, treated by the late Mr John Wiggins, F.G.S., in his treatise on "Embanking Lands from the Sea." I therefore offer no apology for giving the following extracts from Mr Wiggins' book:—

"The various modes by which embanked lands may be brought into a state of cultivation depend chiefly on the nature of the soil. We are therefore now to contemplate an intake securely embanked, with sluices of sufficient capacity to take

off the drainage down to 18 inches below the general level of the surface of the intake. These are essential conditions on which alone the work of cultivation can be commenced with any hope of success, and these conditions being strictly fulfilled, we now proceed to agricultural operations according to the nature of the soil, which may be classed as *clayey, sandy,* and *loamy,* each of which will require a somewhat different treatment in some respects, though in other matters the treatment applies to all. Thus, for instance, in the first agricultural operation,—viz., that of enabling the soil which has so lately been supersaturated with salt water, with all its chemical combinations, to part with so much of its saline and other particles as may be in excess for the purpose of vegetation, or in other words, to *freshen* the soil sufficiently for land plants to thrive upon it,—the process will be the same upon all these soils, and this process consists in forming a series of surface drains by which the drainage waters may run off, carrying with them such portion of the saline and other particles as they may have been enabled to dissolve and take up or absorb.

"But such channels and drains are to be made, not only with the view of freshening the soil, but also in such manner as to answer the ulterior purposes of fences, and of drains to carry off the surface waters.

"The fences of an intake are usually marsh ditches or dykes* of sufficient width and depth to prevent cattle attempting to cross them, and an intake seldom admits of any other description of fence. Such water fences and drains must, in the first place, be drawn all round the intake, *i.e.*, from the sluices by

* Dyke in Scotland means a dry stone wall; in England a ditch.

which the water is to escape along the land side of the sea bank or wall, and along the edge of the higher lands of the adjoining country. Having surrounded the level with these fences and drains, the next operation is to divide it into marshes of such convenient size as may be judged most judicious; and this size will be partly governed by the soil,—clayey soils parting with their salt most reluctantly, and sandy soils most easily. It will also be more strictly governed by the size most convenient for occupation in the particular locality, and also by the desire to save expenses; but in general, sandy marshes may be considerably larger than other soils, and there may even be some advantages in leaving the interior of the level for some time without subdivision, since it will be by no means wise to hasten the process of freshening by sudden saturation, but on the contrary, to allow a considerable period of time to elapse before any thought of cultivation is entertained, and during that period to allow the level to remain *sodden,* only leading the surface waters away gently into the circular dykes already described; and it may be very judicious to fill up the nearest of such hollows with the stuff out of the circular dyke. This soddening or stagnation of the soil in a watery state is considerably more applicable to sandy soils, and to such of those as have before embankment been covered by every tide, than to clayey soils, and will be quite unnecessary in such high fringes or *salts* as have only been occasionally covered by the tide. But the benefits of allowing the soil to remain for a length of time under the influence of stagnant fresh water are great, since it affords time for the decomposition of such animal and vegetable matter as the sea may have deposited in it, macerates

and dissolves the calcareous, shelly, and other such matter, and even reduces the siliceous matter into a state of subdivision resembling clay; and it amalgamates all those heterogeneous particles, takes off their crudities, promotes or prepares them for chemical combination, and reduces them to a state fit for the purposes of fresh-water vegetation. We, however, disapprove any attempt at suddenly freshening the soil, and consider that even the soddening process recommended should be conducted with great care and caution, always gradually, but neither allowing the water to remain too copiously nor too long, nor suffering it to run off too quickly; for this purpose, therefore, cuts or channels should be made from the lowest spots of the level into the circular dyke, so that no water should remain absolutely stagnant if it could be got off, but that at the same time it should only be drawn off gradually. Thus, supposing the whole level could be channelled within the first year after shutting out the sea, and this was done only 12 inches deep, these channels should be allowed to remain at that depth a full summer and winter at least, before deepening them another 6 inches, bringing them to the ultimate depth of 18 inches; gradual freshening and maceration are essential to future fertility, and require a longer time in proportion to the quantity of saline matter, with reference to vegetation, at the period of embankment."

"Thus we have brought the level into this state, viz., it has a marsh dyke or water-fence surrounding it, and very numerous channels throughout its surface leading the waters into the marsh dykes, to the depth of 18 inches below the general surface. The depth of the soil, we may now suppose, has been

somewhat increased by the soil taken from the channels being spread about. By this time several brackish plants, partly of a maritime and partly of a fresh water nature will have appeared, and partially covered the surface; these may be grazed to advantage, and as the surface soil freshens, it may be harrowed, and Dutch clover and rye grass may be sown and rolled in, wherever the absence of other plants may allow of them; first, however, bestowing but a small quantity of seed by way of experiment, and increasing this as success may encourage from time to time. In a period varying from three to seven years, according to the tenacity of the soil and its height above the tide, the level will be fit to bear corn and pulse. If its surface be coarse and uneven, and its soil tenacious and stubborn, or what is called marsh clay, it may be judicious to dig it over and level it at the same time, preserving, however, the channels already dug; taking in the first instance a crop of rape, which might judiciously constitute the first crop, and may either be saved for seed or fed off, and be succeeded in either case by oats, beans, and wheat; but even after the digging of such soils, they will require much tillage, so as to thoroughly mix and pulverise them, and the bean crop should be repeatedly well hoed and weeded. With good treatment, however, such soils bear heavy crops of wheat and beans in succession, and when some degree of exhaustion calls for a relaxation of cropping, the course of fallow, oats, clover, wheat, beans, will give all the produce that can reasonably be expected from any land, the crops very commonly grown on good soils of this kind being eight or ten quarters per acre of oats, four to six quarters per acre of wheat, and about the same of beans.

This produce, however, must not be reckoned on as over the whole surface ploughed and sown with these crops; for at least one-eighth to one-fifth thereof will be still too crude, too salt, too wet, or too stubborn to bear perhaps any crops, or at most but one-fourth of what is borne by the best parts. This drawback, together, with the expenses of cultivating this description of land, soon points out that grass, not tillage, is its most profitable ultimate destination, and accordingly it is found expedient to prepare it for the true and legitimate purpose of an intake, viz., grazing. But we must not fall into the error that because this is the last, it may also be the first destination of the land, a course of tillage being requisite for a time upon all the *argillaceous soils* in order to mix and incorporate them, and to pulverise the soil, so as to bring it into a fit state for the production of the better kinds of grasses, otherwise the coarser will predominate, and the value of the ground be much deteriorated. In proportion, therefore, as the course of tillage is perfect without being continued to exhaustion, and as the levelling and surface draining are well performed, so will be the productive value of the grazing marsh which succeeds the tillage. Nor are these operations sufficient in stiff clayey soils; such will require to have their tenacity subdued or lessened, their working rendered easier, and their pulverisation or admixture of parts more effectual by the application of chalk. This supply of calcareous matter will also act as a manure, and will not only increase its quantity of wheat, but also tend much to improve its quality, to stiffen its straw, so as to prevent or check its lodging, and the consequent deterioration of the grain. In these various ways an expense of L.5 per acre thus incurred will soon be repaid, whilst its beneficial

effects on the soil will last at least twenty years, even under a succession of cropping, but in grass would be permanent."

"The more siliceous soils, whether sandy or loamy, require less chalk if any; and as their texture is apt to be rather too open than too close, lime is often much better adapted to them, if any manure be at all needful, since an intake of soils of this kind generally abounds with shelly fragments, enough to supply the requisite quantity of calcareous matter. It may, however, be well worthy of consideration, whether a supply of lime would not be advantageous in setting to work that calcareous matter, and consolidating the texture of the soil. The period of tillage should be limited to such a space of time as may be sufficient, according to the nature of the soil, to bring it into a fit state for the best grasses to grow to perfection. This, on *stiff clay* lands, may be reckoned as—1, oats; 2, beans; 3, wheat; 4, beans; 5, wheat; 6, clean fallow; 7, oats; and lay this crop down with grass seeds."

"But on good *silty loams* a different mode and duration of cropping may be adopted. Upon such lands, along the coasts of Norfolk and Lincolnshire, the usual course of cropping is,—1, beans; 2, oats; 3, wheat; and they get better wheat after the oats than before, the straw being less bulky, and less liable to 'go down.' But even in the case of such soils, if the argillaceous particles are in such abundance as to produce an unctuous texture, or slipperiness under the feet, when rather wet they may judiciously be subjected to the rotation prescribed for clays, and treated similarly."

"There must, however, be a very great difference of treatment with regard to those slight, loose, sandy soils, of which some spots of the intake level will be found to consist, when taken from

the low slobs of a sandy shore which has been covered by every tide. Such loose sands, *if blowing when dry*, should be fixed as soon as possible by any feedable grass that can be made to grow upon them, until a better sward can be produced. On such loose spots the *Agrostis maritima,* or *seaside fiorin*, has grown luxuriantly, especially when the stolons have been planted in a wet sod of bog turf, and that trodden into the sand. The shoots from these sets have been extremely vigorous; the cattle have sought and eaten them with avidity; and the treading thus induced has fixed the sand, whilst the droppings of the cattle, containing the undigested seeds of other grasses, have soon brought up a good sward wherever the drainage was sufficient for its establishment."

"In such cases of loose sand no tillage can judiciously be contemplated. Such soils are already sufficiently open to part with their excess of saline particles, and are generally sufficiently homogeneous not to require admixture by stirring, unless it be by harrows on the surface to let in the Dutch clover seeds that may, with propriety, be sown thereon, when that brought by cattle shall be permanent enough to show an aptitude in the soil for that plant. These seeds, after being thus sown in moist still weather, should be rolled down, and if the soil has been well drained and freshened, it is more than probable that a good grazing marsh will be established at less expense and in less time than could be effected by any other means, since if the clover thrives, the cattle will lie so constantly on those spots as to enrich them more than any others."

Mr Wiggins concludes by saying, that "the great and leading points for the guidance of the adventurer in reclaiming his in-

take are the following :—To freshen gradually; to drain effectually; to cultivate perfectly; to crop moderately; to look to grazing ultimately; and to lay down to grass carefully."

Even with all the difficulties that beset the subject, there can be no doubt that the daily recurring sight of large tracts of banks left high and dry by the receding tide, suggests the very natural idea of easily excluding the sea and extending the land. It is difficult, indeed, to suppose that any proprietor on the banks of a tidal estuary can be indifferent to such a prospect of adding to his fields, and hence attempts at such reclamation works on varying scales of magnitude are, we may say, almost universal. But though the process may seem easy, and the object very tempting, it is a great mistake to suppose that these estuarial tide-covered banks can, in all cases, be converted into arable or even pasture land at a cost commensurate with their future agricultural value, or to assume that in order to increase the arable land of the country, all we have to do is to steal it from the ocean. On the contrary, as shewn by practical experience, the return for investment of capital on such improvements is always uncertain, and has proved in many cases utterly insufficient. But in all such questions the most reliable and valuable information is that which is derived from practice, and I have therefore been at some trouble to obtain authentic accounts of several reclamations, most of which have been brought under my own notice in connection with navigation works, and I offer no apology for laying them at some length before the reader. These accounts refer, as will be seen, to reclamations formed under very different circumstances as regards locality and construction, and being founded on observations made by reliable independent authorities, who are

personally cognisant of what they state, must be regarded as valuable records of ascertained facts. Some instances will be found of reclamations, on a small scale in favourable situations, being highly satisfactory, while similar works in less favourable localities have not proved so successful. It further appears that the larger class of *modern* reclamations do not as yet seem to have afforded very satisfactory financial results when viewed as agricultural schemes. While the most successful reclamations are those where, in the first instance, the foreshore has been accreted by extensive training walls, constructed to improve navigations, and having the effect of raising the banks on either side of the estuary to the level of high water of ordinary spring tides, and thus rendering the subsequent reclamation-works comparatively easy and inexpensive. In such cases, however, it would be obviously quite fallacious to value the cost of reclamation at the comparatively small outlay required to protect and drain land that has already been raised by navigation works to such a level, as to be covered only by high spring tides. These records will also, I think, be found most fully to bear out the views I have already stated, which may be briefly summarised in the following general propositions:—

First, That in order to insure success, the space to be reclaimed must be within the influence of water containing much alluvial matter, and not on the shores of an open sandy estuary.

Second, That the spaces to be reclaimed should be allowed to receive the deposit left by the tide for as long a period as possible, and the water should not be entirely excluded until they have, by gradual accretion, attained the level, if possible, of high water of ordinary spring tides.

Third, That by properly conducted survey and observations, the amount and fertilising properties of the deposit should be ascertained in order to determine,—*first,* over how many years the process of reclamation is likely to extend; and, *second,* what may be the productive value of the soil deposited.

CHAPTER IV.

EXAMPLES OF TIDAL RECLAMATIONS.

Examples of tidal reclamations at Lough Foyle, Morecombe Bay, the Dee, the Tay, the Lune, the Humber, the Ribble, the Nith, the Forth, and the Tees.—Extent of unreclaimed land in Britain.—Line of conservation for estuarial reclamation works.

Lough Foyle.

The first case which I shall cite is Lough Foyle—a situation where the amount of salt water greatly preponderates over the fresh, and where extensive reclamations have been made under power granted by Act of Parliament. It is, in fact, a pure reclamation scheme, and I have received, from Mr G. Henry Wiggins of Londonderry, some notes regarding it, from which I extract the following interesting information :—After the salt water had been excluded, shallow surface drains were formed, and in about two years rye-grass grew pretty freely, but exceptional spots remained barren for some time. The grass was followed by oats, which improved as the salt left the soil. Deeper draining allowed the cultivation of flax and clover. Afterwards, on still deeper draining, all ordinary crops began to grow well,—wheat, beans, turnips, mangold, and carrots, but all requiring as much manure as any old upper land. These slob lands yield a great return for manure, but must have manure on the lower and damper portions. Fiorin grass grows well without manure.

Whenever the ditches have so far drained the soil as to allow of its becoming cracked and open to the air, the crops begin to increase in produce. But the full value of the soil is never known until thoroughly under-drained with tile or stone; it then yields excellent crops of almost any produce, clover and rye-grass for hay being perhaps the most profitable. Grazing the land does not answer, except from the middle of May to the beginning of September; after this the soil is too cold and damp for the beasts to lie down, and they begin to fail.

The expense of these intakes on the Foyle may be taken at about L.20 an acre to get them from the sea, the expense of bringing the land, when got into cultivation, will come to at least L.10 more, making a total of L.30 per acre. The best lands are worth from 50s. to 40s. the Scotch acre, and the lowest and wettest parts perhaps not more than 10s.—say 30s. as a fair average. To this has to be added the expense of keeping up the banks and pumping water. The above remarks may be held generally to refer to reclamations made about the same time on Lough Swilly, and certainly do not present encouraging views as to these reclamations viewed as a mercantile speculation.

Morecambe Bay.

The reclamations made by the Ulverston and Lancaster Railway in Morecambe Bay were rapidly formed by the embankment for carrying the railway, which was made in pretty deep water. Like the Foyle, there is also a great predominance of sea water. From G. Drewry, Esq., of Holker, in Lancashire, I have been favoured with the following information :—A portion of the land enclosed by the railway in 1856 was grassed over, and the remainder was

sand without any vegetation on it. After it was levelled it was divided into fields by open ditches and iron fences. The ditches had to be made very wide at the top in order to get them to stand. The land was then drained with 3-inch pipes, each drain opening into the ditch on each side of the field. The tiles were embedded in peat moss, to act as a filter to prevent the sand running into them. The sand is so fine that, without this precaution, the drains would have filled up very quickly. The drainage is the great difficulty, as the pipes are very apt to fill up after every precaution has been taken.

On the portion which was grassed over before it was enclosed two crops of oats were first taken, and then it was green cropped. It grew for a few years good crops of wheat, beans, and clover, as well as Swedish turnips and mangolds, but though a great quantity of manure was used the crops fell off, and at present it is nearly all in grass. The portion which was bare sand when it was enclosed was treated in the same way, except as to the first two crops of oats. It was green cropped after it had been enclosed about two years. After the railway was made there was no means for silting that portion of the enclosure which was sand. The tide was entirely kept out. Had it been admitted the lands would have been much more valuable and much higher. We would then have had better drainage and a richer soil. That portion which was grassed over at the time it was enclosed is still much the best.

When land is reclaimed from the sea, the first thing to be looked to is a good outfall for the water, and when it is possible no doubt it is very desirable that the land should be silted up gradually. In our case this could not be done, as the reclama-

tion of the land was a very secondary affair, it being a railway, and not a reclamation scheme.

The Dee.

I have already described the works of the River Dee Company. My own opinion is, that had they been originally designed as low rubble training walls to guide the channel by judicious lines through the estuary, instead of confining it by a high embankment to the south side, it would not only have been better for the navigation, but more for the interests of the Dee Company. However, the following extract from a letter addressed by W. J. Hamilton, Esq., the chairman of the company, in 1845, to the Tidal Harbours Commission, who were then holding an inquiry at Chester, describes the financial position of the company as follows* :—" The citizens of Chester, not having either the means or inclination to make any efficient improvements of their harbour, certain individuals, afterwards incorporated as the River Dee Company (in 1732), undertook to do so on having, as a compensation for the outlay of their capital, a grant of the White Sands, then of no value whatever, with the right of imposing tolls for the use of the improved navigation. Upon this agreement the undertakers laid out nearly L.80,000—a large sum one hundred years ago—in making the present channel and outlets for the river in lieu of the numerous streams through which the river at that time flowed over the estuary, upon which outlay the original subscribers received no dividends or return for nearly the first fifty years, and those who have since represented

* Tidal Harbours Commission, 1845, p. 318.

them have been receiving a dividend gradually increasing to 4½ per cent. per annum, which is now at last paid on each L.100 of original stock. Had that capital been originally invested at interest in the Government Funds, or upon mortgage, it would, at the end of the first fifty years, during which no return was received upon that expenditure of capital, have amounted to a sum far above the present value of the River Dee Company's estate.

"This statement of facts will, it is hoped, be sufficient to satisfy yourself and your colleagues (the letter is addressed to Admiral Washington) "that the company's bargain has not been so highly beneficial to them, nor so very prejudicial to the citizens of Chester, as has been represented. I do not think it necessary to refer further to the additional outlay incurred by us from time to time after the original expenditure of L.80,000 in improving and maintaining the present navigation, but I will rest satisfied with assuring you that the River Dee Company has derived no other return from that outlay than the dividend before stated, and such prospect as they have of gradually and slowly, and not without additional expenditure of capital or income, reclaiming farther portions of this estuary."

The Tay.

I have already referred to Sir John Richardson's experience on the Tay, where the enclosures, on account of the limited depth of water, and the favourable circumstances in which they were made, were much more likely to lead to satisfactory results than the cases I have cited. The water of the estuary of the Tay, where Sir John Richardson's reclamations were made, is highly charged with alluvial matter, the slob lands are on a

pretty high level, and there were one or two small islets in front of the property separated from the shore by shallow channels, all contributing to successful reclamation. Sir John Richardson has kindly communicated the following notes regarding them:—

The first faggot dyke was run across to Cairnie Island in 1808-9, and 50 reclaimed acres (Scots) were under crop in 1826. The first crop was oats, which was rent free, and it paid the whole cost of the embankments (L.1400). The first ten years were alternately white and green crops, and had one or two dressings of lime, but no manure was required, and then a four shift rotation commenced. The *reclaimed* land continues to be more fertile than the adjoining land, which is also of excellent quality —less manure is required for the reclaimed land, as some virgin soil continues to be blended with the upper stratum when the land is ploughed. To make it *perfect* it requires a little more silica to strengthen the straw, which is scarcely stiff enough to stand upright in a favourable season. On the whole, the operation has, in my case, been extremely profitable, and when exhausted it can be refreshed by warping with the tidal waters.

The Lune.

Aldcliffe Marsh lands, on the Lune, extending to 160 acres, were enclosed in 1820, and I am indebted for the following notes regarding them to the proprietor, Edward Dawson, Esq. of Aldcliffe Hall. "The land enclosed was previously an old marsh, a good part of it covered with rushes. As it approached the tide there was more silt, and it was partly covered with sward and pastured with sheep.

"The whole was ploughed in 1821, being the spring after its

enclosure, and sown with oats, which proved a very fine crop. This was succeeded by a four-course rotation, and continued in crop till 1855, when it was gradually laid down in grass, as more profitable than the cultivation of corn. It still remains in grass, with the exception of ten acres. I consider the land quite equal to the ancient enclosed land."

This enclosure refers to land having had a long period for accretion, being an "old marsh." The training walls on the Lune, which were completed in 1851 by Messrs Stevenson, have had the effect of fixing the channel, so as to allow the marshes to extend their limits, but no additional land has been enclosed by embankments in consequence of the navigation works.

The Humber.

The Humber, as already noticed, is a river largely charged with alluvial matter, and Mr Oldham states the following as his experience, in the 'Proceedings of the Institution of Civil Engineers:'—"Soon after the exclusion of the tidal water the marine grasses and vegetation begin to die and decay, and in the course of one or two years fresh-water grasses appear; after the lapse of about three years a tolerably good surface of pasture is naturally formed. But that which is most surprising is the spontaneous appearance and the growth on the enclosures of Sunk Island of an entire covering of white clover, which presents itself within three or four years of the date of the exclusion of the salt water. Where the land is destined for crop the first sown is rape, about the third or fourth year after the enclosure, and the produce is usually of extraordinary quantity and vigour. The following season oats or beans may be sown, and then

wheat; and perhaps of all districts of England the largest and best crops may be found on Sunk Island, for the tenants admit that the land produced upwards of six imperial quarters of wheat per acre. Flax also is produced of a fine and valuable quality, and in large quantities. The producing power of this description of land is not limited to the growth of cereals or fibrous products, but the finest roots, such as potatoes, turnips, mangold wurzel, &c., are successfully cultivated. The climate is mild through the winter, but it is hot in summer. The rainfall averages 18 inches per annum, and the harvest is frequently from one to two weeks earlier than in the surrounding country." Mr Oldham states the cost of the reclamation of these lands as varying from L.5 to L.20 an acre.

The Ribble.

It would be difficult to find a case presenting more favourable features for easy and profitable reclamation, on a reasonable extent, than the Ribble, in Lancashire.

The Ribble Navigation Company in 1838 obtained an Act for the improvement of the river, under the advice of Messrs Stevenson, by whom the works were afterwards executed.

The only portion of these works to which it is necessary at present to refer is the guiding of the river by low rubble training walls, which confined the navigable channel to a fixed course, and, at the same time, allowed the tidal water to flow freely over the banks on either side of the estuary, as will be understood by referring to figure 7, at page 28. The anticipated effect of this was to encourage the deposit of rich alluvial matters on either side of the estuary, and as this deposit would no longer be subject to encroachments by the river, it was expected that

ultimately a belt of marsh land would be formed all along the shores. The Act directed that a plan of the banks of the estuary should be made before the commencement of the works, and that a similar plan should be made every tenth year thereafter, showing the quantity of land gained from the river within each such period of years. It further enacted that at the end of every successive ten years three persons should be nominated—one by the Ribble Navigation Company, another by the owners of the adjoining land, and the third by the two persons so nominated—as arbiters to fix the quantity of land so gained, to settle its value, and fix the annual rents to be paid to the company by the landowners.

By a subsequent Act, obtained in 1852, the company were directed to make a statement of the amount of land then gained, and at the end of every five years thereafter; and landowners were declared to be entitled to the right of pre-emption in the event of their wishing to become owners of the reclaimed land *ex adverso* of their property.

Mr Garlick, engineer to the Ribble Navigation Company at Preston, has kindly furnished me with the following details, showing how this arrangement has been carried out, and its results:—

	A.	r.	p.
Up to the year 1853 there had been regained, .	913	2	4
1853 to 1858, ...	760	1	12
1858 to 1863, ...	590	1	18
1863 to 1868, ...	335	0	2
Total, .	2599	0	36

"Generally, but not in all cases, the landowners fronting the reclaimed land have claimed the right of pre-emption. With the

exception of two portions, almost the whole of the land reclaimed by the company's works remains open out-marsh, and is covered at high tides."

"Sir Thomas Hesketh purchased the reclaimed land in Hesketh on the south side of the river, and has excluded the tide from about 700 acres by a sea embankment. Half of this land was the new reclaimed land, and the other half was out-marsh in 1838, when the Navigation Company got their Bill."

"On the land embanked in at Hesketh there have been immense crops of all kinds of farm produce, and the land has let at a high rent. There was a heavy crop of wheat the first year after the exclusion of the tide."

"The frontagers in Freckleton and Newton, on the north side of the river, did not claim the right of pre-emption, and the reclaimed land became vested in the Ribble Company, who seven years ago embanked 550 acres of this new land; and the tide has been excluded from it ever since."

"The land of the company in Freckleton and Newton was, as soon as embanked, let on a lease for twenty-one years in one farm at a yearly rental of L.3 per statute acre, the tenant paying rates and taxes, and doing all other work, the company maintaining the embankment. In the spring of the year, after the tide had been excluded from the land, it was ploughed and cropped with oats, potatoes, carrots, and turnips, and all were good crops. In the second year wheat was an excellent crop, and all sold for seed, turnips and carrots were extra good crops, oats and barley, ryegrass and clover very full, asparagus plentiful and rich—beans sufficient in straw, but yielded nothing, being the only exception to the productiveness of the land. This

second year the Royal North Lancashire Agricultural Society held the trial of all kinds of implements on the farm. The rotation of cropping may be stated as green crop, wheat, rye-grass and clover, oats, then green crops again; but in this part of Lancashire the rotation depends altogether on the seasons, which are so variable as to affect the state of the land, and necessitate changes in the intended course of cropping. That part of the reclaimed land embanked which has been lately devoted to pasture has grassed satisfactorily. Flowers, strawberries, gooseberries, apples, &c., grow in the gardens, and indeed almost everything that is grown on a cropping farm flourishes on this reclaimed land when enclosed from the sea. The land here alluded to was mostly grassed over before being enclosed (being nearly at the level of high-water of spring tides), and the foregoing observations as to cropping must be considered as referring to such enclosures, and not to low raw land from which the tide has been early excluded."

The Nith.

Low training-walls were constructed by Messrs D. & T. Stevenson on the Nith for the improvement of the navigation, which were completed in 1863. Part of the wall extended in front of a bay of slob land belonging to the estate of Kirkconnell, and I have a letter from A. Maxwell Witham, Esq., the proprietor, in which he says:—"The training-walls which you put in the River Nith have greatly improved the navigation." The effects of these works on the foreshore of Kirkconnell, after an experience of 10 years, Mr Witham describes as follows:—"What was formerly marsh has not been enclosed; it remains as before.

Some portion of what was formerly slob has gradually and very slowly grassed over. No part has been enclosed, or is ever likely to be. The cost of embanking to keep out the spring tides would be too heavy. Moreover, such land pays best in the short grass which grows on it, impregnated as it is with salt from the tidal water."

The Forth.

For an interesting account of the enclosures at Tulliallan, on the Forth, I have to refer to the paper by the late Mr William Menzies, in the Society's Transactions, already quoted. The first reclamation, of 152 acres, was completed in 1823. The second, of 220 acres, was completed in 1838. Mr Menzies' paper, which was written in 1838, does not treat of the financial results of these works, and I applied to Mr John Menzies, of Inch farm, to learn if he could throw any light on that branch of the inquiry. In reply to my letter, in speaking of the last made reclamation, of which he has the most knowledge, he says "it cost the estate between L.18,000 and L.20,000. As a speculation, I am afraid you cannot say it pays. My father did everything in the shape of bringing the land reclaimed under cultivation, and I have heard him express the opinion that it never came to carry crops until it was once properly swarded with grass, and if he had sown it all out at first it would sooner have yielded him some return. It never paid him as a tenant."

The Tees.

Two extensive reclamations have been made on the Tees in connection with the navigation works of the River Tees Conservancy Commissioners, and Mr Fowler, the engineer of the Commissioners, has given me the following information regarding them.

The accretion at Haverton has been going on since 1837, and was induced by the groins erected by the Navigation Commissioners. In May 1860, after a lapse of twenty-three years, the foreshore having been raised to the level of high-water of neap tides, the works of enclosure were commenced, and in February 1863 the water was excluded from 150 acres of land at a cost of L.9800, including interest on the outlay, but exclusive of any allowance for the cost of the navigation works. Seventy acres of this land were grazed in 1867, and cropped with oats in 1868, and subsequently with grass, oats, carrots, and potatoes. Eighty acres were sold for manufacturing purposes at L.8626, 14s. The portion under tillage is rented at L.200 per annum.

The Eston and Tod Point reclamations were commenced in 1869, and the water was excluded in 1871 from 585 acres, at a cost of L.16,494, special facilities having been offered for making the embankments of slag from the iron furnaces. About one-half of the land is grassed over, and the other half is sand, and the whole enclosure was valued by arbitrators as available for manufacturing purposes at L.113,925.

Neither of these reclamations can be viewed as agricultural improvements, the chief inducement being to obtain sites for public works, and they probably would never have been undertaken but for the facilities afforded by the expensive works of the Navigation Commissioners, and the refuse from the iron-works.

Such are the results of some important reclamations made under different physical circumstances and financial arrangements. To what extent the estuarial shores of the country can be further reclaimed, so as to prove profitable agricultural specu-

lations, without injury to navigation, is a very wide question, of which engineers take different views.

Mr Hyde Clark, in a paper on the "Engineering of Holland," published in Weale's Quarterly Papers in 1844, says—"The following moderate estimate will show the large area available for the enterprise of our capitalists and the skill of our engineers :—

England—	Humber, &c.,	40,000	acres.
	The Wash,	60,000	„
	Suffolk and Essex,	40,000	„
	Hampshire and Dorsetshire,	10,000	„
	The Severn,	30,000	„
	Cheshire and South Lancashire,	50,000	„
	Morecambe Bay,	40,000	„
	The Duddon,	10,000	„
	Solway,	20,000	„
		300,000	„
Ireland—	Loughs,	300,000	„

"The total extent in the two countries cannot be estimated at less than 1000 square miles, or 600,000 acres, worth at the lowest average L.20 per acre, though most of it, as in Morecambe Bay and Lough Swilly, would be worth L.60 per acre."* The total value of reclaimed land would be between twelve and twenty millions sterling.

I give these figures to show what large views have been propounded as to the practicability and prospective value of reclamations on the shores of this country. But I think some of the facts I have stated on the authority of gentlemen intimately acquainted with the details of each case regarding reclamations *actually made,* such, for example, as Lough Foyle, Lough Swilly,

* The information I have received, it will be seen, does not warrant such a conclusion.

Morecambe Bay, the Forth, and the Dee, do not present much encouragement as to the prospective value of enclosures made on a large scale; whereas such enclosures as those on the Tay and the Ribble, where the deposit was not unduly hastened, but left to the gradual action of the tide, are found to afford satisfactory results. Moreover, Mr Clark's views, as his paper indicates, are given apparently irrespectively of the interests of navigation, as he seems to contemplate reclaiming the shores even of the Mersey, though he very truly adds that to make such an attempt would create a "panic." Now, however important it may be agriculturally to gain acres from the sea, it can never, in my opinion, be justifiable to convert sea into land to the detriment or injury of the free navigation of our rivers and harbours, and it must ever be a duty of our Legislature to see that navigation is not sacrificed to agricultural speculation. But I have, I think, shown that the extent to which reclamation can be carried as a *profitable* agricultural speculation is really very limited, and that if such reclamations are made on sound engineering principles, they do not necessarily interfere with navigation.

In accordance with these views, I stated in the first edition of my treatise on River Engineering, published in 1858,—"With reference more particularly to the operations of landowners, it is notorious that in many cases attempts to reclaim or protect property have led to serious and costly legal proceedings between landowners and the local conservators of navigations; and this, we are sensible, has in some instances arisen from a feeling on the part of the landowners that their operations could not be regarded as prejudicial. The local conservators, on the other hand, have generally no means of knowing what the ultimate intentions

of the landowners are until their operations have proceeded so far as to render it impossible, if the interests of navigation require it, to stop or to remove the works without considerable loss. A difference of opinion has thus been raised, which has too often ended in an expensive lawsuit. We have long held the opinion that it would in many, if not in all, of our estuaries be most desirable to have a line of conservation marked out by the Admiralty (without whose authority no encroachment can be made within high-water mark),* for the regulation of all works for the protection of land. Were such a line defined, the landowners could then with confidence, and without risk of challenge, enter on such works within the line of conservation as they considered necessary for the protection of their property, and a source of much difference of opinion and expensive litigation would be at once removed. It is obvious that were such a duty to be performed, it must be committed to a duly qualified commission, so composed that the protection of navigation and the interests of landowners should be fully represented."

Since that date a Royal Commission has determined the legal boundary-line between sea and river salmon fishings in all the estuaries of the kingdom. This was a delicate duty, affecting the rights of many proprietors, and settling questions that had long afforded ample discussion and many trials in the law courts, but it has been done by the Salmon Fishery Commission. I do not see why, in many cases at least, a similar commission should not usefully be employed in deciding in what estuaries reclamation is consistent with the interests of navigation, and if so, to what extent it may be carried.

* This authority is now vested in the Board of Trade.

CHAPTER V.

THE DEFENCE OF SEA-SHORES AGAINST THE ACTION OF THE WAVES.

Works should not be of an aggressive character, but purely for defence.—Rubble moles.—Groins.—Continuous line of piling with occasional low jetties.—Drainage of Reclamation Works.

In more open and exposed estuaries than those we have been considering, and all along the exposed sea-shores of the coast, the works of reclamation or protection assume a more formidable aspect, and must be considered under the *fourth* branch of the subject, viz., *Defence of sea-shores against the action of the waves.*

The first remark I have to offer on this subject is, that in all cases of such exposure the works should never be of so *aggressive* a character as may be prudent in sheltered estuaries, as it is a dangerous policy to attempt to encroach on the sea-coast within high-water mark, excepting with works of a solidity and cost proportionate to what they have to resist, and this, I may safely say, will, in almost all instances, be found to be greatly in excess of the agricultural value of the land reclaimed. In illustration of this, I may quote a case where a road had been formed along a sea-beach for a considerable distance round the boundary-wall of valuable agricultural property. In this case I found it advis-

able, on investigation, to recommend the proprietor to abandon the acquired tide-covered space, and relinquish a portion of his arable land as a site for a new road on solid ground, and to build new fence-walls, as being far less costly than a sea-wall sufficient to protect the roadway against the possible damage due to the coincidence of heavy storms with high spring tides. It is no doubt true that by the erection of costly groins and other works, such as at Sunderland, Leith, and elsewhere, land has been successfully gained for the construction of docks. But the expense in such cases has ranged from L.2000 to L.3000 an acre. It is also true that the engineer is often called on to construct extensive sea-walls for the protection of roads and railways involving interesting questions of marine engineering, but it is obvious that such works cannot with any propriety be considered as belonging to agricultural engineering, and do not fall to be considered here. There are, however, tracts of country raised but little above the high-water level, and, therefore, liable to be submerged during excessive storms, where works, not of *aggression*, but purely of *defence*, are not only warranted, but are essential for the protection of agricultural land. I may refer, in illustration of what I mean, to one case on the shores of the Bristol Channel, where large tracts of low-lying pasture, extending for a distance of about five miles along the coast, are the most valuable lands in the country, bringing exactly twice the rental of the tillage lands in the district. These low-lying lands, though above ordinary high-water level, are nevertheless exposed, when high winds and high tides coincide, to be flooded by a very prejudicial inundation, and would, if not protected, ultimately lose their present high value as pasture land. This,

then, belongs truly to those cases of *defence*, and not of *aggression*, which I conceive may be legitimately dealt with in the prospect of the result, even in an agricultural point of view, being satisfactory; and on such cases I have still to offer a few observations.

Where rubble stones, as they come from the quarry, can be cheaply procured, they will be found, in most cases, very valuable

Fig. 8.

as a defence against inroads of the sea. The proper size of the rubble, unless the exposure is very great, may vary from one to three cubic feet, and should have a sufficient quantity of smaller pieces to fill up the interstices. A trench should be cut in the beach as a foundation for the rubble mole, and the stones should be deposited roughly, without being built or arranged. The stuff excavated in forming the foundation should be thrown up inside of the mole, and mixed with stones, shivers, or quarry rubbish, as a backing for the rubble stones. The land above the mole should be sloped back and turfed, or sown with grass seeds,

and after storms any of the rubble that has been drawn down by the waves should be at once replaced with additional rubble, till the whole has acquired stability.

The accompanying cut, fig. 8, shows the nature of this work as actually executed by Messrs D. and T. Stevenson, on a pretty extensive scale, to protect carse lands in exposed situations, and I refer to it as a style of defence, varied, of course, to suit particular exposures and localities, which may very generally be successfully applied where stone can be easily procured.

In some places, such as the mouth of the Humber, the inroads of the sea have been successfully resisted by occasional groins run out from the beach; and it may, in many cases, be prudent, as a first measure, to ascertain the effect of groins, as in the event of their proving successful the expense of any continuous line of defence may be saved. In so far as my own experience goes, however, isolated groins do not generally prove a satisfactory defence, and have to be supplemented by longitudinal work of some description. I may, as exemplified in several places where groins have been tried on the shingle beaches of the southern shores of England, refer to one instance of this coming within my own experience at the Bristol Channel, already noticed, where jetties run out at right angles to the high-water line had long been tried without good result. I found that in heavy seas the waves were led along the jetties, and struck with great force in the corner where they joined the beach at high-water mark. I further found that the shingle of which the beach is composed was heaped up on the *western* sides of the groins by prevailing westerly winds, while it was heaped up on the *eastern* side of the groins by winds which had prevailed from

the east. The groins, therefore, in that particular situation, did not tend to encourage a uniform deposit of shingle, which shifted from side to side, according to the wind, while the exposed face of the groin, from which for the time the shingle had been removed, acted most injuriously by presenting a decoy to the sea right up to high-water mark. These *high* isolated jetties were therefore removed, and a continuous line of piling, parallel to high-water mark, was substituted, presenting no obstacle to the run of the waves along its surface. Occasional lines of *low* jetties were put in front of the higher continuous pilework to arrest the shingle, and the ends of these low jetties were at some places, where the scour of shingle was greatest, connected by lines of low piling parallel to the higher continuous piling; and this mode of construction has proved very successful, not only in encouraging a more uniform collection of shingle, but also in preventing the run of the sea, during high tides, overtopping the shingle beach and deluging the adjoining lands. In proof of this I may state that, on making an examination after the occurrence of an unprecedentedly heavy storm, accompanied by high tides, I found that wherever the continuous upright piling and planking had been constructed, there was no influx of anything beyond spray upon the adjoining land, but that at all other parts of the coast (which is about six miles in length), where the face of the beach was sloping, and the upright piling had not been applied, the water passed freely over in considerable depth, carrying drift timber far into the fields, and in some places heaping up heavy shingle on the land to the depth of two or three feet. It was evident, therefore, that the problem to be solved was to oppose an obstacle which should *throw back* the

sea, even at the risk of its beating somewhat heavily on the face of the pilework and rising in pretty heavy spray above it, provided the passage of large bodies of water on the low-lying land could be prevented. The cuts 9 and 10 show this work

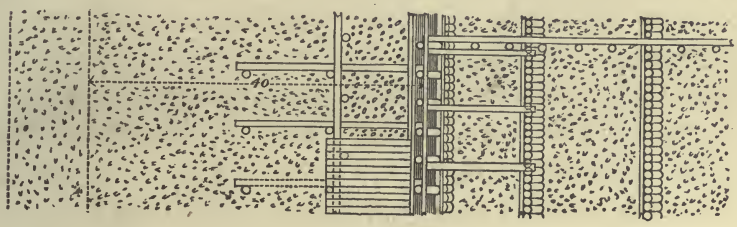

Fig. 9.

as it was executed in plan and section, from which it will be seen that the main defence against the inroad of the waves consists of a continuous line of nearly perpendicular piling and planking, rising to the height of nine feet above high

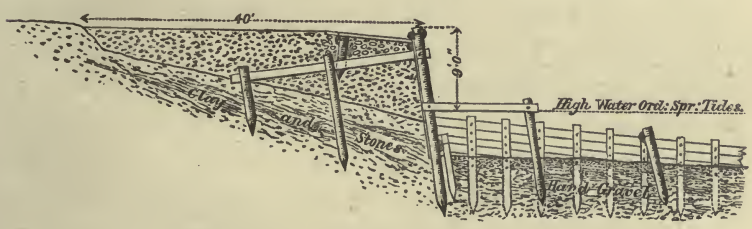

Fig. 10.

water, while the shingle is encouraged to collect in front of this line of timber walling by low groins and lines of connecting stakes, forming rectangular inclosures, in which, when the shingle is deposited, the waves seem to have no tendency again to scour out.

Occasional reference has been made to drainage, and this is, perhaps, the natural place to say *generally*, that in all such cases of estuarial reclamation and coast defence as we have been considering, it is essential that the engineering works should embrace a proper system of drainage. Main and cross drains, of sufficient capacity and fall, must be formed and led to one or more outlets through the embankments. The outlets of these drains must be provided with self-acting sluices, to close at high tides, but to afford an escape for the drainage at low water. The discharge of such drains, it need hardly be added, must vary in every case with the drainage area and rainfall of the district to be provided for, and their sufficiency to discharge the requisite amount will depend on the fall that may be found available; and whatever that may be, it will regulate the cross sectional area of the drains themselves. The whole of the works of the drainage should be carefully designed, on due consideration of the *meteorological*, *geographical*, and *engineering* features of each separate case, and the offlets, tunnels, pipes, and sluices should be executed under proper supervision.

Much of the success of such drainage works, I may add, depends on the selection of a favourable site for the discharge of the drainage water, especially on exposed beaches composed of shingle or gravel. The force of this remark may perhaps be well illustrated by a reference to the rivers Findhorn and Lossie, on the Moray Firth, where the shingle is thrown up by the sea in such quantities as completely to overpower them, and consequently these rivers discharge into the sea at points very distant from what might be regarded as the natural position of their outlets. Fig. 11 shows this action at the Findhorn; and fig.

12 the same action at the Lossie, both on the shores of the Moray Firth; and in both cases it will be seen that the outlets of the rivers are driven to the westward, the heaviest seas on that coast being caused by easterly and north-easterly gales; and if this be so in the case of large rivers draining large districts of country, it must be obvious that the discharge of drainage water connected

Fig. 11.

with ordinary agricultural improvements on sea-coasts having a similar geological formation, must be more liable to interruption, and should therefore be carefully considered. In proof of this, I may state that I have known a drainage outlet, constructed at a large cost near the high-water mark of a shingle beach, rendered quite inoperative by the same heaping up of shingle as I have described. The current was altogether unable to force a

passage through it, and an outlet had periodically to be made by manual labour, at considerable expense, to prevent flooding of the land. Whereas, had the outlet been formed on a lower level, and carried out to low water, it would not only have been clear of the detrital matter thrown up by the sea, and forming the line of beach, but would have had the advantage of the

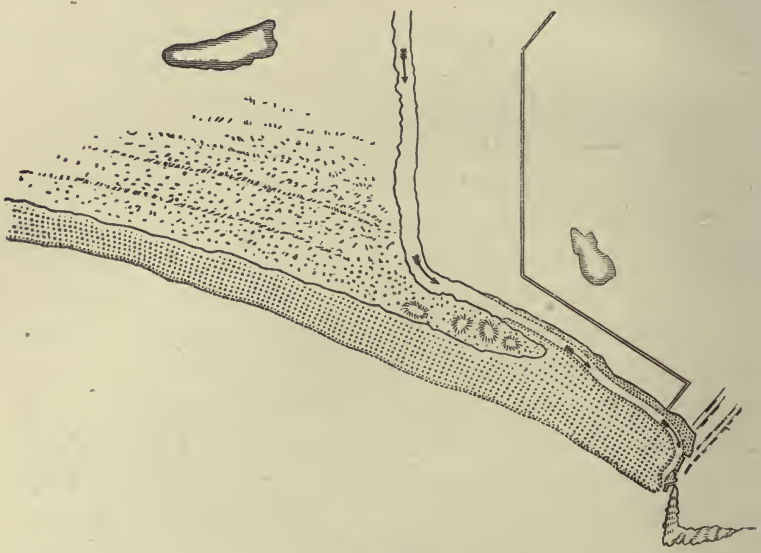

Fig. 12.

greater scour due to additional head at low water to remove any obstructions that might be thrown up opposite the outlet.

In addition to what may be properly styled works of defence against aggression, and may therefore legitimately be regarded as coming within the province of ordinary agricultural engineering, the section of the subject we are now considering

naturally embraces those gigantic reclamations which now form large portions of Holland and Denmark, and the Fen districts of England. I do not, as stated in the outset, propose to treat of such undertakings, which can only be accomplished by national resources or by powerful public companies. The protection of Holland, a country which has been called "the gift of the ocean," is believed to have cost upwards of L.300,000,000 sterling. The sea-dykes of Schleswig and Holstein, in Denmark, are stated to protect about 900,000 acres.* The Romney Marsh, the first of England's reclamations, has an area of 70,000 acres. The Fen lands of Lincoln and Norfolk are computed at 600,000 acres. But, to learn the history of these gigantic English reclamation and drainage operations, the reader must refer to the writings of Sir W. Dugdale in 1652,† and of W. Elstobb in 1793;‡ and interesting details regarding the reclamations in Holland and Denmark are to be found in papers in the Proceedings of the Institution of Civil Engineers, by Mr John Paton, C.E.,* and Mr John Henry Muller of the Hague;§ and also in Mr Hyde Clarke's paper on the Engineering of Holland, in Weale's Quarterly Papers.

It is well to notice, however, that though these extensive schemes differ from the more humble works we have been considering, as regards the larger area reclaimed or pro-

* On the Sea Dykes of Schleswig and Holstein. By John Paton, C.E., Min. of Proc. of Institution of Civil Engineers, 1862.

† History of Embanking and Draining of divers Fens. By Sir W. Dugdale, 1652.

‡ A Historical Account of the Great Level of the Fens. By W. Elstobb, engineer, Lyne, 1793.

§ On Reclaiming Land from Seas and Estuaries. By John Henry Muller, Min. of Proc. of Institution of Civil Engineers, 1862.

tected, the general principles on which all such works are based are of universal application, so that, in fact, the same conditions, engineering and agricultural, apply to the defence of a few fields on a farm exposed to the sea, as to the protection of Holland, which, equally with the smaller work, owes its existence to the constant watching and maintenance of its sea defences. But, of course, the similarity being only in *condition*, and not in *degree*, the actual difference between the two classes of works is very great. The mere fact that, in addition to the drainage of such enormous districts, viewed simply as an engineering question, the safety of thousands of inhabitants of large towns has to be provided for, gives to the reclamation schemes of such countries as Holland—with all their sea-dykes, sluices, canals, and pumping engines—an importance that undoubtedly places them in the foremost rank of hydraulic engineering works.

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